THERMAL CONDITIONING FOR INTEGRATED CIRCUIT TESTING

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FIELD OF THE INVENTION

[0001] One or more aspects of the invention relate generally to thermal conditioning for testing of integrated circuits.

BACKGROUND OF THE INVENTION

[0002] Conventionally, automated test equipment ("ATE") is coupled to a temperature forcing unit. A thermocouple is attached to an outer surface of encapsulation material used to package an integrated circuit die to form the microchip, and is attached to the temperature forcing unit. A technician then manually adjusts temperature of the temperature forcing unit. The temperature forcing unit may be set to force air at any temperature within a range of temperatures. A target temperature is known as the "set point." The amount of time allotted to allow the microchip to reach thermal stability is known as the "soak time." Once set point and soak time are set, airflow is flowed from a temperature forcing unit over the microchip. The thermocouple attached to the microchip is used to provide temperature feedback information to temperature forcing unit. Conventionally, several adjustments of the temperature forcing unit are made in order to obtain a target temperature for purposes of testing the microchip under thermal stress. Additionally, the type of thermocouple may be specified as part of the setup procedure.

[0003] Accordingly, this type of thermal conditioning provides a temperature of the material encapsulating the microchip, which given sufficient time is assumed to conduct throughout the microchip. However, when thermally stressing an integrated circuit, it would be desirable to know the temperature at the p-n junctions of the semiconductor material used to form the die ("junction temperature"), and not just the temperature of the encapsulation material. In other words, it

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would be more precise to know the temperature of the die itself. This would provide a more precise thermal understanding of thermal budget. Furthermore, it would be desirable if the amount of technician intervention could be reduced in order to further automate the process.

SUMMARY OF THE INVENTION

[0004] An aspect of the invention is thermally conditioning a microchip. A temperature target is set. The microchip is thermally conditioned responsive to the temperature target over an interval of time. A diode voltage of a diode of the microchip is measured. A diode temperature is determined responsive to the diode voltage measured, and the diode temperature is compared with the temperature target to determine a temperature error. This thermal conditioning may be repeated, where interval times are adjustable responsive to temperature error, until a stabilization band is reached.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Accompanying drawing(s) show exemplary embodiment(s) in accordance with one or more aspects of the invention; however, the accompanying drawing(s) should not be taken to limit the invention to the embodiment(s) shown, but are for explanation and understanding only.

[0006] FIG. 1 is a high-level block diagram of an exemplary embodiment of a test system having a microchip under test.

[0007] FIG. 2 is a high-level block diagram of an exemplary embodiment of a computer system having a programmed computer.

[0008] FIG. 3 is a flow diagram depicting an exemplary embodiment of a temperature control flow.

[0009] FIG. 4 is a time versus temperature graph depicting an exemplary embodiment of a thermal profile for the temperature control flow of FIG. 3.

[0010] FIG. 5 is a schematic/block diagram depicting an exemplary embodiment of a microchip.

[0011] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures.

DETAILED DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 is a high-level block diagram of an exemplary embodiment of a test system 100 having a microchip 104 under test. Test system 100 includes a programmed computer 105, temperature forcing unit 101, tester 102 and an integrated circuit test card/data interface bus 103. Notably, a thermocouple, which conventionally would be attached to microchip 104 in a thermal test system, is not needed in test system 100. One end of air supply line 106 is connected to temperature forcing unit 101 and is used as a conduit for a temperature controlled airflow to microchip 104. The other end of air supply line 106 is connected to air housing 107 (sometimes referred to as a "sealing cup") to distribute temperature controlled air over microchip 104. Temperature forcing unit 101 and tester 102 are coupled for communication with computer system 105. Microchip 104 is coupled via data interface bus 103 with tester 102 for communication.

[0013] FIG. 2 is a high-level block diagram of an exemplary embodiment of a computer system 105 having a programmed computer 210. Programmed computer 210 includes a central processing unit (CPU) 211, memory 212, a variety of support circuits 214, and an input/output (I/O) interface 213. CPU 211 may be any type of microprocessor known in the art. Support circuits 214 for CPU 211 may include conventional cache, power supplies, clock circuits, data registers, I/O interfaces, and the like. Memory 212 may be directly coupled to CPU 211 or coupled through I/O interface 213, and I/O interface 213 may be coupled to a conventional keyboard, network, mouse, display printer, and interface circuitry adapted to receive and transmit data, such as data files and the like.

[0014] Memory 212 may store all or portions of one or more programs or data to implement processes in accordance with one

or more aspects of the invention. Additionally, those skilled in the art will appreciate that one or more aspects of the invention may be implemented in hardware, software, or a combination of hardware and software. Such implementations may include a number of processors independently executing various programs and dedicated hardware, such as application specific integrated circuits (ASICs).

[0015] Programmed computer 210 may be programmed with an operating system, which may be OS/2, Java Virtual Machine, Linux, Solaris, Unix, Windows, Windows95, Windows98, Windows NT, and Windows2000, WindowsME, and WindowsXP, among other known platforms. At least a portion of an operating system may be disposed in memory 212. Memory 212 may include one or more of the following: random access memory, read only memory, magneto-resistive read/write memory, optical read/write memory, cache memory, magnetic read/write memory, and the like, as well as signal-bearing media as described below. One or more aspects of the invention may be implemented as program products for use with computer 210. Program(s) of the program product defines functions of embodiments in accordance with one or more aspects of the invention and can be contained on a variety of signal-bearing media, such as computer-readable media having code, which include, but are not limited to: (i) information permanently stored on non-writable storage media (e.g., read-only memory devices within a computer such as CD-ROM or DVD-RAM disks readable by a CD-ROM drive or a DVD drive); (ii) alterable information stored on writable storage media (e.g., floppy disks within a diskette drive or hard-disk drive or read/writable CD or read/writable DVD); or (iii) information conveyed to a computer by a communications medium, such as through a computer or telephone network, including wireless communications. The latter embodiment specifically includes information downloaded from the Internet and other networks. Such signal-bearing media, when carrying computer-readable instructions that direct functions of one or more aspects of the invention, represent embodiments of the invention.

[0016] Memory 212 may store all or a portion of test vectors and target test results 222. Stored in memory 212 is temperature control flow 223.

[0017] FIG. 3 is a flow diagram depicting an exemplary embodiment of a temperature control flow 223, and FIG. 4 is a time versus temperature graph depicting an exemplary embodiment of a thermal profile 400 (not drawn to scale) for temperature control flow 223. Note that while FIG. 4 shows a thermal profile where the temperature of a device being tested is increased, the present invention is equally applicable to decreasing temperatures. Temperature control flow 223 is described with simultaneous reference to FIGS. 1, 2, 3 and 4.

[0018] At 301, an initial temperature target is set. At 302, air is flowed from temperature forcing unit 101 over microchip 104. This flowing of air is in response to a control signal from computer 210 to temperature forcing unit 101 in response to temperature control flow 223. This air flow is temperature controlled to force microchip 104 to reach the initial temperature target.

[0019] At 303, temperature control flow 223 waits for a preset time A. Preset time A is an initial stabilization interval 402, and will depend on temperature target, starting temperature of microchip 104 and size of microchip 104, among other variables. For example, such an initial stabilization time may be approximately 240 seconds. Initial stabilization should be sufficiently long in duration so as to accelerate reaching the target temperature set at 301 without significantly exceeding such target temperature. The force temperature used at 302 conventionally will exceed the target temperature of 301, and thus an approximation for initial stabilization time interval 402 is a sufficient time for microchip 104 to reach the force temperature of 302.

[0020] At 304, diode voltage is measured. FIG. 5 is a schematic/block diagram depicting an exemplary embodiment of microchip 104. Microchip 104 includes at least one diode 503 electrically accessible via an input pin 501 and an output pin

502. Diode 503 may be formed with formation of the integrated circuit of microchip 104.

[0021] A known level of current is provided to input pin 501 of microchip 104 from tester 102 via data interface bus 103. Tester 102 is configured to provide such a fixed current responsive to a control signal from computer 210 under control of temperature control flow 223.

[0022] Voltage, V(T), across diode 503 is dependent in part on junction temperature, T. For voltage, V(T), in volts and temperature, T, in degrees Celsius, the equation for temperature T may be expressed as:

$$T = (A - V(T))/B, \qquad (1)$$

where A and B are constants. Constants A and B are empirically determined, as is known. For example, A may be approximately 0.74325 volts, and B may be 0.0018227 volts per degree Celsius. These are merely example values for A and B, and many other values for A and B may be empirically determined as is known. Conventionally, A equals voltage V(T) when temperature T is equal to approximately zero (0) degrees Celsius and current is set to some fixed level. Thus, for example, current may be set to approximately 100 micro-Amperes for determining A. Accordingly, the known level of current supplied to microchip 104 from tester 102 is approximately the same level of current for determining A. Voltage, V(T), which is a function of temperature, T, is a measurable value. Accordingly, by measuring voltage V(T) with known values for A and B, temperature, T, may be determined. In an embodiment, V(T) is a measured voltage from output pin 502 obtained responsive to supplying a known level of current, and thus voltage V(T) provides an indication of junction temperature of diode 503.

[0023] After measuring diode voltage at 304, junction temperature is determined at 305 using Equation (1). At 306, temperature error is determined by subtracting temperature determined at 305 from the target temperature of 301. Notably,

though temperature error in this example will be a negative number for measured temperature 410, where target temperature is within tolerance band 401, it is possible to have measured temperature immediately after stabilization interval 402 to be below a target temperature. However, for purposes of clarity, the embodiment according to FIG. 4 is described, though other thermal profiles may be used. Thus, initial stabilization sub-flow 331 is completed.

[0024] At 307, the temperature target is revised by adding temperature error of 306 to temperature target of 301. As, in this example, temperature error of 306 is a negative number, the revised temperature target will be lower than the initial temperature target.

[0025] At 308, thermal forcing unit 101 is instructed by computer 210 under control of temperature control flow 223 to force to the revised target temperature of 307. At 309, temperature control flow 223 waits for a preset time B. Preset time B is a coarse adjustment interval. For example, such a coarse adjustment interval time may be approximately 60 seconds. Coarse adjustment interval should be sufficiently long to avoid an excessive number of coarse adjustments prior to reaching a temperature error threshold. Furthermore, if not enough time is allowed for temperature stabilization, it is equivalent to having no feedback at all, and the temperature may increase without bound for hot temperature testing (or decrease without bound for cold temperature testing). This may result in damage to the device being tested and/or the test equipment being used to apply the test conditions, whereas waiting longer does no harm.

[0026] At 310, diode voltage is measured, as previously described with respect to block 304. At 311, temperature is determined, as previously described with respect to block 305. At 312, temperature error is determined by subtracting the revised target temperature of 307 from the determined temperature of 311.

[0027] At 313, it is determined whether the temperature error is within plus or minus a percentage of the revised target temperature. This percentage, for example, may be approximately ten percent (10%). If temperature error is outside of tolerance at 313, then temperature error of 312 is added to the revised target temperature of 307 to provide a newly revised target temperature. Accordingly, there may be one or more coarse adjustments for coarse adjustment sub-flow 332, and thus one or more coarse adjustment B intervals which in totality define coarse adjustment interval 403.

[0028] If, however, at 313 it is determined that temperature error is within tolerance, then at 314 temperature control flow 223 waits for a preset time C. Preset time C is a coarse stabilization interval. For example, such a coarse stabilization interval time may be approximately 300 seconds. Notably, during coarse stabilization interval 404, temperature of microchip 104 may go out of an acceptable error range, and thus a fine adjustment sub-flow 333 is used.

[0029] At 315, the target temperature is revised. This may be done by using the last target temperature from 307 and adding to it the last temperature error determined at 312.

[0030] At 316, thermal forcing unit 101 is instructed by computer 210 under control of temperature control flow 223 to force to the revised target temperature of 315. At 317, temperature control flow 223 waits for a preset time D. Preset time D is a fine adjustment interval. For example, such a fine adjustment interval time may be approximately 30 seconds. Fine adjustment interval 405 should be sufficiently long at to avoid an excessive number of fine adjustments prior to reaching a temperature within tolerance band 401.

[0031] At 318, diode voltage is measured, as previously described with respect to block 304. At 319, temperature is determined, as previously described with respect to block 305. At 320, temperature error is determined by subtracting the revised target temperature of 315 from the determined temperature of 319.

[0032] At 321, it is determined whether the temperature error determined at 320 is within a threshold tolerance, such as stability band 401. If temperature error of 320 is not within tolerance, then fine adjustment sub-flow 333 repeats at 315 using the then temperature error of 320 to update a revised target temperature from an immediately previous iteration temperature target revision 315. If, however, temperature error determined at 320 is within tolerance, namely, sufficient thermal stability is obtained, testing of microchip 104 is initiated at 322.

[0033] At 323, it is determined if testing is completed. If testing has not been completed, temperature control flow 223 loops back to 323. If, however, it is determined that testing is completed, then at 324, diode voltage is measured, as previously described with respect to block 304, and at 324 the measured diode voltage is recorded. At 325, temperature control flow 223 ends.

[0034] It should be appreciated that interval times are adjusted responsive to temperature error to proceed from a coarse adjustment loop to a fine adjustment loop. To accelerate the coarse loop adjustment, a thermal initialization interval is used. Additionally, a coarse stabilization interval may be used between the coarse and fine adjustment loop to ensure thermal stability prior to refined adjustments toward reaching a stabilization band. It should be appreciated that a thermocouple device connected to microchip packaging need not be used. In other words, thermal conditioning may be done without such a thermocouple device.

[0035] While the foregoing describes exemplary embodiment(s) in accordance with one or more aspects of the invention, other and further embodiment(s) in accordance with the one or more aspects of the invention may be devised without departing from the scope thereof, which is determined by the claim(s) that follow and equivalents thereof. Claim(s) listing steps do not imply any order of the steps. Trademarks are the property of their respective owners.